The Diurnal Constituent

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1 The diurnal constituent

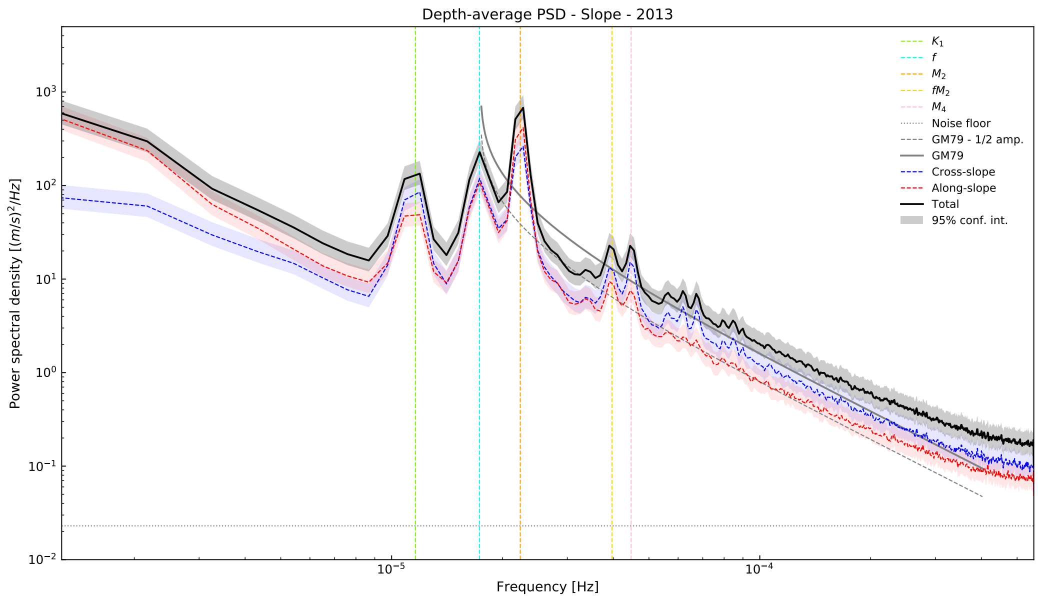
To do: Find more studies of diurnal signals over a slope. Investigate vertical scales. Quantify my results and compare to quantities in reading. Look at shelf wave structure.

Barotropic diurnal (K_1) tides are associated with the astronomical motions of the Earth, Moon, and Sun, and manifest as a zonally propagating 'surface' tide approximately once per day (Stow et al., 2019). For the Earth's major bodies of water, the barotropic tide is restricted to ocean basins as a cyclonically (anti-cyclonically) propagating wave in the northern (southern) hemisphere, forcing regional tidal currents when it passes (Stow et al., 2019). As these currents interact with irregular topography such as a shelf, sea-mount, or canyon, internal tides are generated which radiate outward through the stratified ocean interior; these are the baroclinic, or internal, diurnal tides (Stow et al., 2019). **this may be too general and already part of the Introduction**

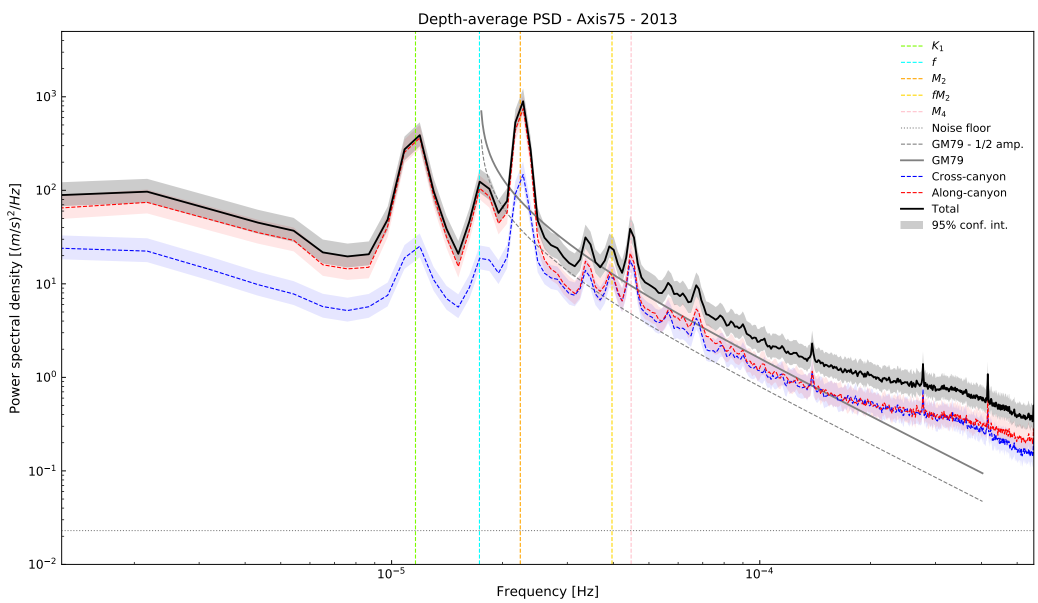
The diurnal signal is one of three dominant frequency constituents in the observed spectra at both Upper Slope and Axis, along with the Coriolis parameter, f, and the semi-diurnal tide, M_2. Based on annual depth-averaged power spectral density data (Figure 1), at Upper Slope K_1 is equivalent to or slightly weaker than f in depth-average power (between $1-2\times10^2$ (m/s)^2/Hz), and just less than half the strength of M_2, as expected from previous observations of tidal constituents on the Vancouver Island Continental Shelf (VICS) (Thomson et al., 1990; Allen et al., 2001). At Axis, the depth-average annual K_1 signal is about 3×10^2 (m/s)^2/Hz, approximately twice as strong as f and half the strength of M_2, slightly stronger than at the slope due to local near-bottom canyon enhancement, to be discussed (Kunze et al., 2002).

Seasonally, at both sites there are observed pulses of increased diurnal energy, with the most notable from April to August, corresponding with an expected annual switch to NW, upwelling-favourable winds (Figure 2) (Thomson & Krassovski, 2015). A second, more segmented pulse occurs each winter, November through February, and appears to correlate with increased regional storm activity*. **need more discussion of weather contributions to VICS regional dynamics**

The spring-neap cycle appears to modulate the strength of the diurnal signal at both sites, evident in two-week periodicity. **show this with a comparison to barotropic tides / depth-mean time series / tidal model**



(a) Upper Slope



(b) Axis

Figure 1: Depth-averaged PSD data for (a) Upper Slope and (b) Axis, in 2013, for rotated, cleaned, and WKB-scaled velocity data. Shown are total (black), cross- (blue), and along- (red) slope/canyon spectra. The expected GM spectra for Barkley Canyon are in black (total) and dashed-black (1/2 amplitude). A chi^2 95% confidence interval is show for each spectrum. Additionally, primary tidal-constituents and the instrument noise floor are shown for each site.

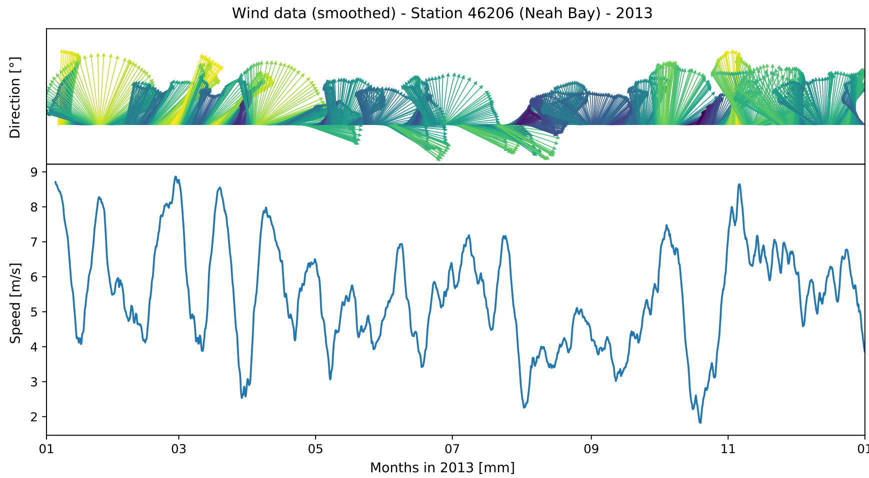
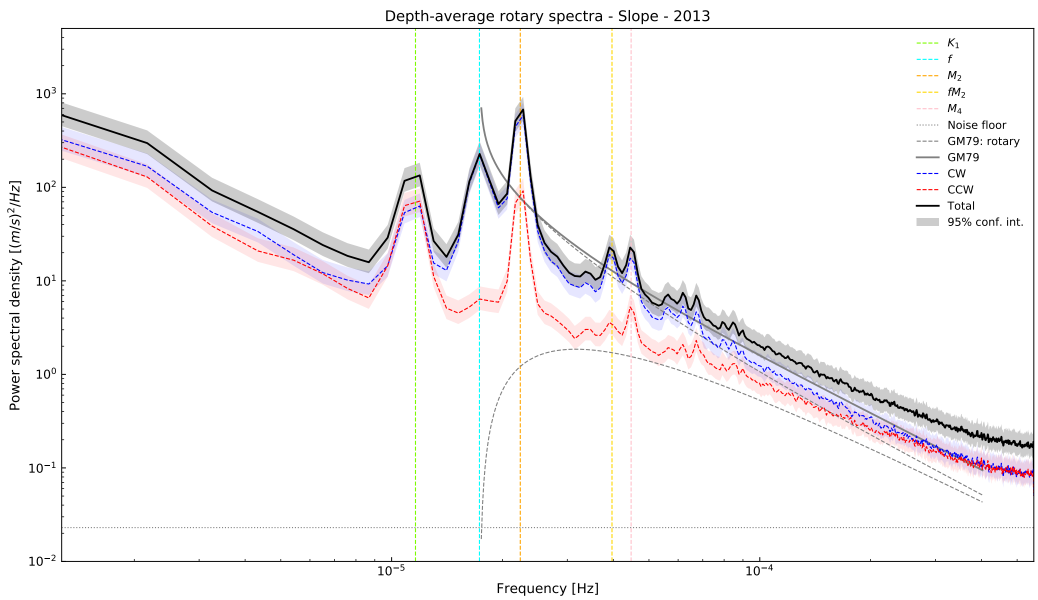


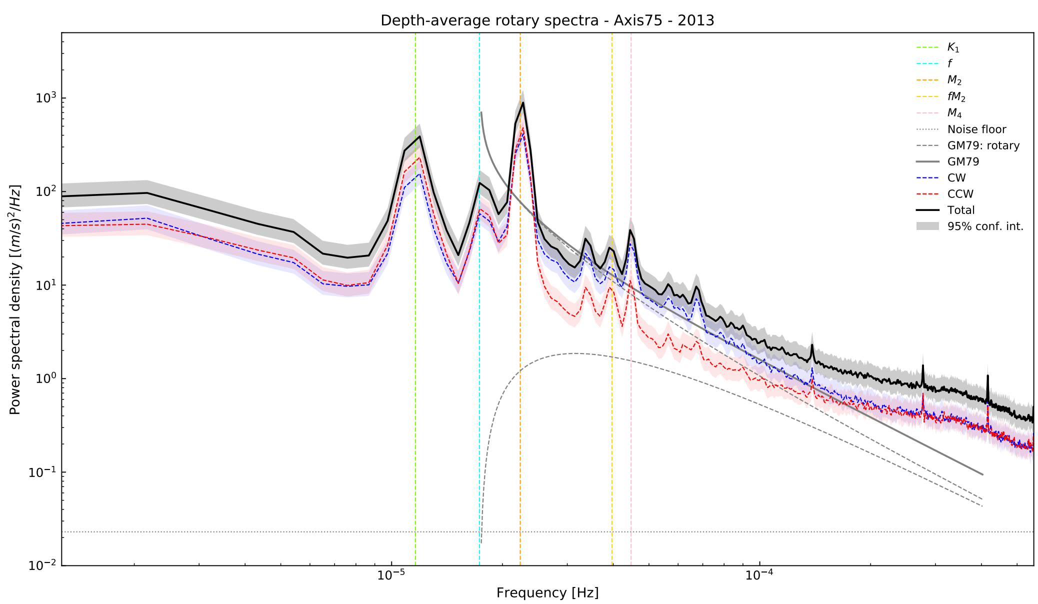
Figure 2: Smoothed wind data for 2013, obtained from the Neah Bay DFO buoy 46206. The upper frame shows intensity and direction (North is up), with intensity/speed as indicated in the lower frame. **these wind figures need to be properly smoothed using wind-vectors**

From directional depth-band integrated power spectra (Figure 4), at Upper Slope there is a switch in the dominant direction of K_1 from cross-slope, above about -250 metres, to along-slope, below. At the mouth of the nearby Strait of Juan de Fuca, coastally trapped waves (CTW) are generated and propagate poleward, mostly as Kelvin waves, along the coast of Vancouver Island, with the descending VICS as an external boundary to the generated baroclinic tidal currents (Crawford & Thomson, 1982). CTW are depth- and boundary-dependent, and travel with signature vertical structure and speed (Cummins et al., 2000), easily distinguished from barotropic constituents which have nearly uniform vertical structure (Robertson et al., 2017). It is possible that these CTW propagating NW along the shelf are contributing to the observed diurnal activity, as they drive strong along-slope currents that become cross-slope near to canyon topography at the shelf edge (Crawford & Thomson, 1982), as observed above -250 m at Upper Slope. Additionally, the cross-slope signal appears correlated to the CW rotary component (Figure 5), as expected for diurnal propagation over a shelf in the northern-hemisphere, due to Coriolis effects (Cummins et al., 2000; Kuroda et al., 2018). Furthermore, the signal enhancement during the spring/summer switch to NW, upwelling-favourable winds is characteristic of the regional CTW, which have been found to experience enhanced generation during this period (Thomson & Crawford, 1981). **need to support some of this with quantities; do mine compare?**

Still at Upper Slope, but below -250 m close to the shelf edge, the along-slope



(a) Upper Slope

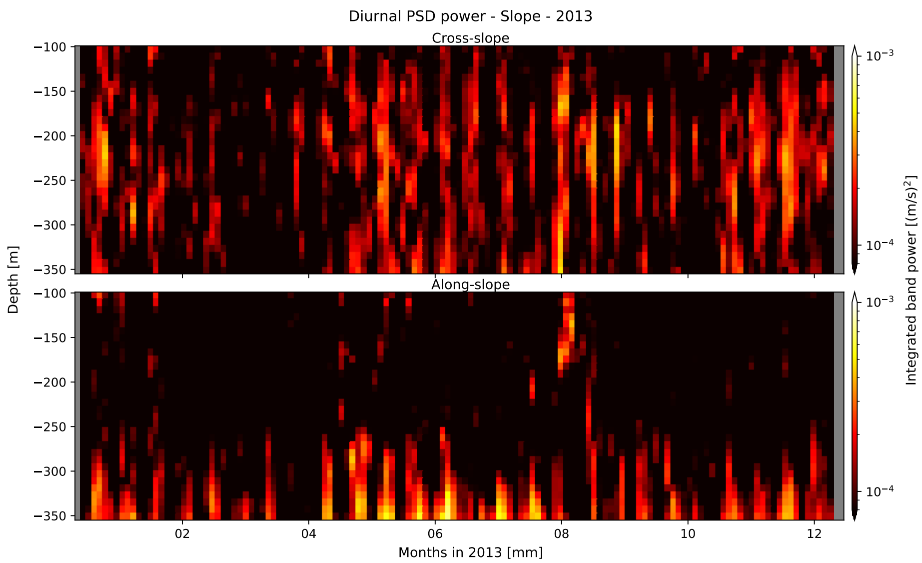


(b) Axis

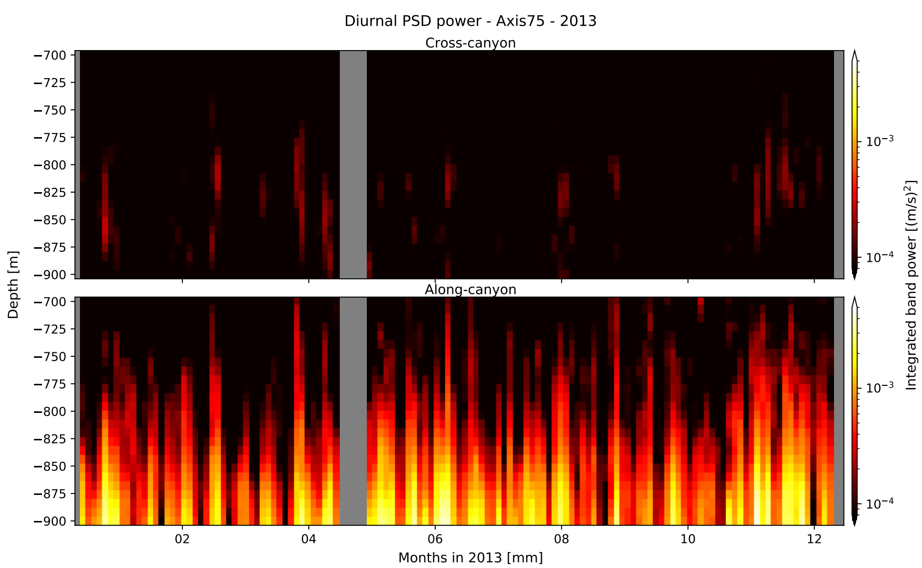
Figure 3: Depth-averaged rotary data for (a) Upper Slope and (b) Axis, in 2013, for rotated, cleaned, and WKB-scaled velocity data. Shown are total (black), CW (blue), and CCW (red) slope/canyon spectra. The expected GM spectra for Barkley Canyon are in black (total) and dashed-black (CW (upper) and CCW (lower)). A chi^2 95% confidence interval is show for each spectrum. Additionally, primary tidal-constituents and the instrument noise floor are shown for each site.

signal increases in magnitude and overtakes the cross-slope. **quantify** The signal may be showing effects related to the cyclonically propagating barotropic diurnal tide in the north-Pacific basin (Cummins et al., 2000). As the NW diurnal tide moves along the slope, evanescent internal waves are generated which are restricted to a region immediate to the generation site*. At this latitude (48.38°N), the diurnal tidal constituent (1.15×10^{-5} Hz) is sub-inertial (local f being 1.73×10^{-5} Hz), and so lies outside of the bandwidth for free internal waves within the frequency boundaries of f and $N - N$ being the stratification dependent Brunt–Väisälä or buoyancy frequency(Johnston & Rudnick, 2014); this prevents locally forced diurnal internal tides from propagating too far from their source. As such, it is notable that there is a prominent baroclinic signal evident both over the shelf and in the deep canyon. Indeed, the strong along-slope signal near the shelf is also evident in the CCW rotary component, in the same depth range, suggesting upward propagation due to the nature of vorticity in the northern-hemisphere*; this supports the theory of a potentially slope-generated evanescent baroclinic diurnal signal. **this needs plenty of expansion, and further research into the vertical scales of such an event**

At Axis, the diurnal signal is nearly entirely in the along-canyon direction, equally distributed between the CW and CCW components as expected for canyon-focused rectilinear flow (Kunze et al., 2002). As the canyon narrows near its floor, the rectilinear flow is enhanced as it is squeezed through the narrow passage of the Axis site; there is an increase in the depth-band integrated power by a factor of about 10×, an order of magnitude, as observed by Kunze et al. (2002) in Monterey Canyon. Similar to the shelf edge effects at Upper Slope, diurnal tidal flow through the tight canyon axis and along its irregular topography could force evanescent internal waves, possibly evident in the enhanced diurnal signal near the canyon bottom*. Interior canyon topography, such as corners, ridges, and the narrowing walls, are known to be sources of baroclinic diurnal tide generation (Kunze et al., 2002). Additionally, as the presence of canyon topography can drive a cross-slope flux of diurnal energy associated with CTW, it is possible that some of this flux may be diverted into the canyon as it passes over (Thomson & Crawford, 1981). Though CTW currents diminish as the slope gets progressively deeper, heading offshore, they have been found to be largely intact above -1000 m (Thomson & Crawford, 1981), so even the deep Axis site is within their boundaries, though within the confines of the canyon walls. **vertical scales of canyon generated internal waves? can CTW effects make it into the canyon? expand and do more research!**

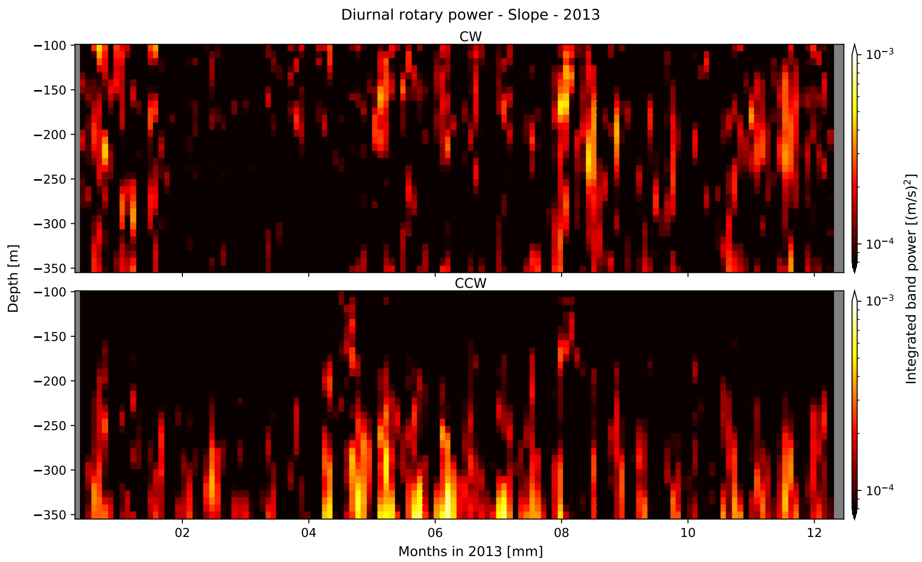


(a) Upper Slope



(b) Axis

Figure 4: PSD depth-band integrated power for (a) Upper Slope and (b) Axis, in 2013, for rotated, cleaned, and WKB-scaled velocity data. Shown are total cross- (upper) and along- (lower) slope/canyon plots for each site.



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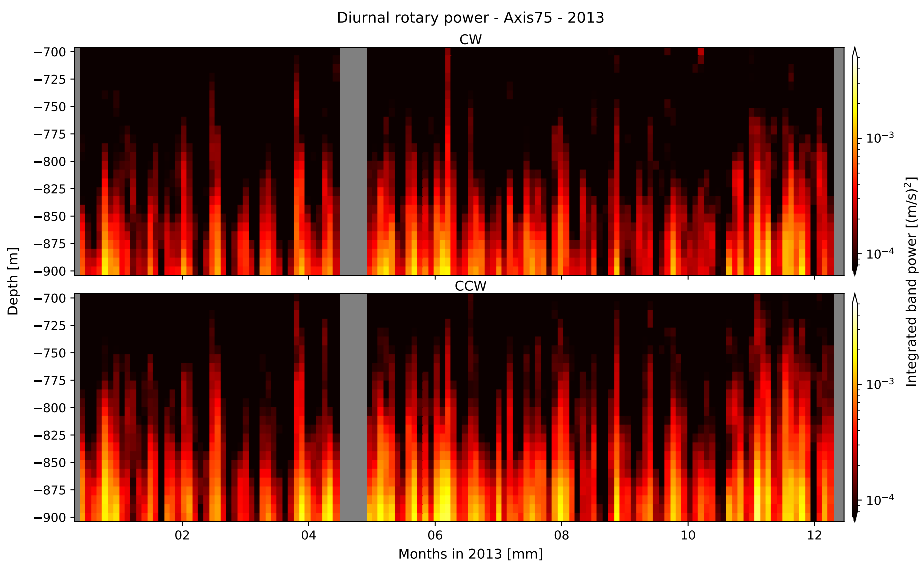

(b) Axis

Figure 5: Rotary depth-band integrated power for (a) Upper Slope and (b) Axis, in 2013, for rotated, cleaned, and WKB-scaled velocity data. Shown are total cross- (upper) and along- (lower) slope/canyon plots for each site.

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